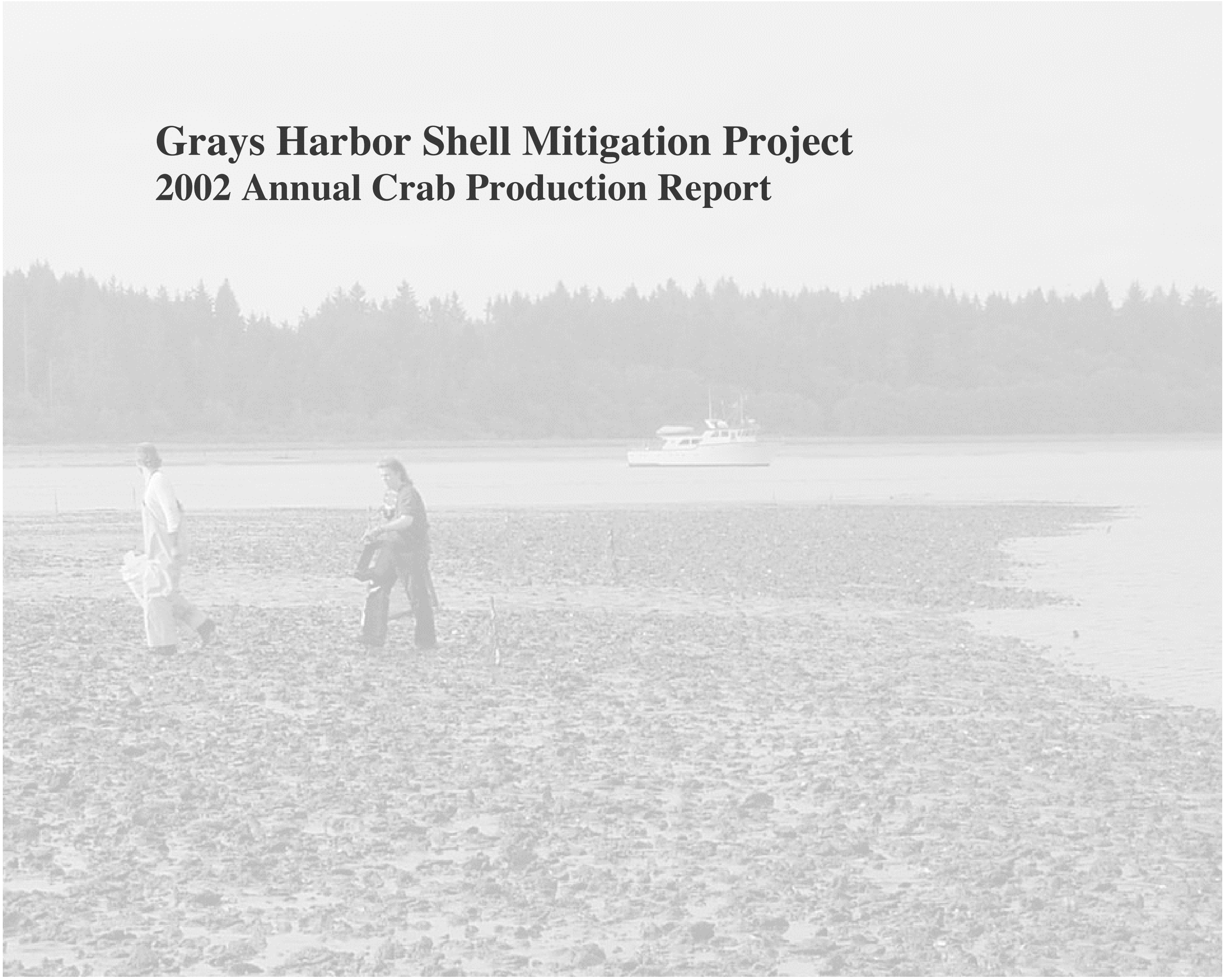
Grays Harbor Shell Mitigation Project
2002 Annual Crab Production Report



FINAL REPORT

May 2003

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PROJECT OVERVIEW

The shell mitigation project for replacement of Dungeness crabs during dredging of shipping lanes through Grays Harbor has been ongoing since 1990, when test plots were first constructed, and in full since 1992. The original impetus for the mitigation project was a widening and deepening of the major navigation channel through the estuary, with corresponding impact on the resident crab population in the channels. The original estimate was that this construction dredging phase killed approximately 650,000 one year old equivalents, or 1-4% of the average annual commercial crab landings for the state of Washington (Wainwright et al. 1992). The concern over dredging impacts was particularly strong in Grays Harbor since the port of Westport typically shows the greatest Dungeness crab catch statistics in the state. After much negotiation, habitat mitigation was eventually chosen as the means of attempting to replace lost crabs. A total mitigation goal of 9 million was set to compensate for the construction dredging (and account for natural mortality until the juveniles produced by the artificial habitat could reach legal fishery size). The idea was to create artificial habitat for the juvenile crabs, thereby decreasing mortality due to predation and increasing survival through the most vulnerable period of life history and increasing recruits to the fishery which were lost during dredging. Ongoing maintenance dredging continues to impact the crab population and drive mitigation efforts. For background and history of this project, as well as descriptions of procedures and pictures, please refer to the original papers describing the inception of the program (Armstrong et al. 1992, Dumbauld et al. 1993 and 2000). Details of the procedures used as well as the yearly project status can be found in the 2000 and 2001 Grays Harbor Shell Mitigation Project Reports (Visser 2001 and 2002), as well. Both Grays Harbor status reports have complete descriptions of background, life history, and field protocol, and the 2000 report has pictures of the field site, new and old shell habitat, and the field crew processing the samples. 2002 procedures were identical to previous years, except for the dates sampled (Table 1). Field crew personnel this year consisted of Mary Aleshire, Kristine Gladson, Kevin Palmer, Cyndie Sundstrom, Jesse Undem, and William White.

Table 1. Sampling dates, times, and tidal heights for data collection during summer 2002 at South Channel mitigation sites.

Date	Low tide time	Low tide height
26-May	7:57 AM	-2.6
27-May	8:43	-2.8
28-May	9:28	-2.5
29-May	10:12	-2.1
11-June	8:31	-2.1
12-June	9:12	-2.3
13-June	9:54	-2.3
10-July	8:10	-2.4
11-July	8:53	-2.6
12-July	9:35	-2.6
8-August	7:47	-2.3
9-August	8:31	-2.5
10-August	9:13	-2.4

Note: Times and heights given are for Aberdeen, WA. Standard corrections for Westport are -0:56 minutes and -1.6 feet. Since the South Channel site is about half way between Westport and Aberdeen, actual times for the mitigation plots are about -0:28 minutes and -0.8 feet from those listed in the table above.

CURRENT STATUS AND STATISTICAL ANALYSIS

Shell placement decisions for the 2003 new shell mitigation habitat are underway. 12,000 yds^3 will be placed, which should provide approximately 40,000 - 67,000 hectares of shell habitat, assuming an average of between 3.3 - 5.6 m^2 per cubic yard of shell, which was realized in 1999 and 2000. A cooperative arrangement was attempted with an advanced senior statistics class at Clarkson University, whereby we would hopefully gain some additional insights into our long-term dataset and the students would get some experience working with actual field data. The students (Stephen Conover, Randall Fitsik, and Jennifer Patti) were familiar with MiniTab software and thus ran correlation regressions using this program as a data mining process to look for multiple factors which may be contributing to shell plot productivity, as opposed to direct hypothesis testing. These cursory analyses of production data from 1990-2001 by William Hooper's statistics group revealed three distinct groups of plots based on historical production (using J4 as the production unit as per historical aggreement).

Group 1: 1992, 1995I, 1996, 1996/1997, 1999O, 1999Up, and 1999Down
Group 2: 1994, 1995, 1996W, 1997E, 1997W, 1998, and 2000East
Group 3: 1990, 1996E, 1999O/D, 2000Up, and 2000Down

The simple regression model:

Total Prod /Yr = 36.2 •G1shell + 51.0 •G2&3shell - 225516 G1 - 168316 G2 - 28508 G3

had an r^2 of 0.624. A more complex model, which includes as factors more of the available data, must be pursued to explain more than 62% of the variability in J4 crab production. While tidal elevation was correlated to total production of J4 instars, it did not significantly increase the r^2 of the MiniTab model and was dropped from the model. Both temperature and precipitation data were tested against crab production results and no correlation was found. Perhaps their effect on larval supply is too long-ranging in time and distance to correlate well with monthly sampling data. Age of shell (number of years since construction) did not contribute significantly to the model and was discarded as a factor. Patchiness of shell distribution, edge effects, size of plot created, and overlay versus bare substrate were deemed not statistically testable by the statistics group working on these data during winter 2002-2003 due to lack of sufficient data (see Table 2).

Table 2. Factors attempted in statistical analysis, source, and findings. The source of all data except for temperature and precipitation is collection by field personnel on the shell plots. Environmental data came from NOAA web data sets giving monthly values for the Chehalis River and Grays Harbor County.

Factor influencing production	Finding by Hooper's group
area covered by shell	significant correlation with production
plot location	apparent correlation based on geographic location
early settlers	no significant contribution, dropped from model
month of sampling	no significant contribution, dropped from model
temperature	no significant contribution, dropped from model
precipitation	no significant contribution, dropped from model
age of shell	no significant contribution, dropped from model
tidal elevation	correlated with locations, not added to model
patchiness	insufficient data
edge effects	insufficient data
eelgrass coverage	not tested
size of plot created	not tested
overlay	insufficient data

The residuals of the model versus time show a cyclical pattern which merits further investigation (Figure 1). Particularly, the majority of the deviation about the mean occurs prior to 1998. A more rigorous statistical approach will be pursued and hopefully more of the information contained in these data will be brought to the surface. Many of the differences between the early phase of the mitigation project (1992-1997) and the current period (1998 - 2002) could be as a result of the declining presence of *Hemigrapsus oregonensis* on the shell mitigation plots.

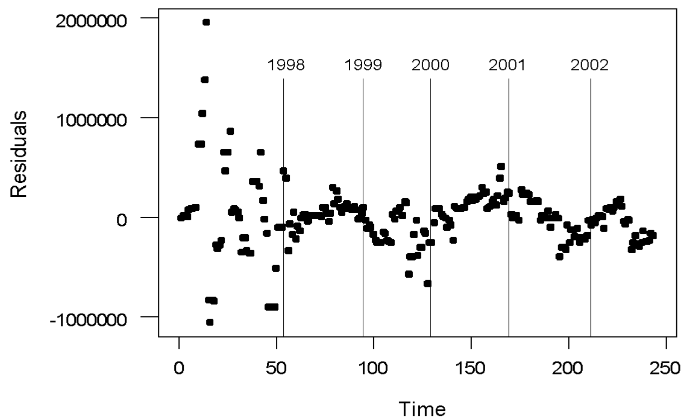


Figure 1. Magnitude of residuals versus data points over time from the MiniTab model of J4 Production against percent shell cover data, from Hooper et al. summary report.

SIGNIFICANT FINDINGS

Tidal elevations and depth contouring

A new and extensive survey of the shell mitigation site was undertaken by the Shoalhunter crew during summer 2002 with tighter spacing of survey paths than existed previously (Figure 2). This was necessary to resolve the depth contours and locate the positions of the channels accurately. These depth data enabled good approximations of tidal elevations for each plot to be determined (see Table 3), which in turn enabled analysis based on tidal elevation to help in locating optimal sites for shell placement. Subsequent analysis using McadContour, including hand correction of the depth contour lines between survey paths, shows the shape of the elevation contours (Figure 3).

Table 3. Ranked order of shell plots according to tidal elevation, feet above MLLW.

Plot	feet	n
1992	1.91	100
1994	1.41	463
1999Up	1.21	270
2000East	1.08	78
2000Up	1.03	88
1997W	0.92	97
2000Down	0.79	178
1998	0.55	48
1996/97	0.52	273
1999Down	0.32	315
1996W	0.27	70
1997E	0.05	177
1999O/D	-0.02	100
1995	-0.17	168
1995I	-0.47	185
1995M	-0.86	90

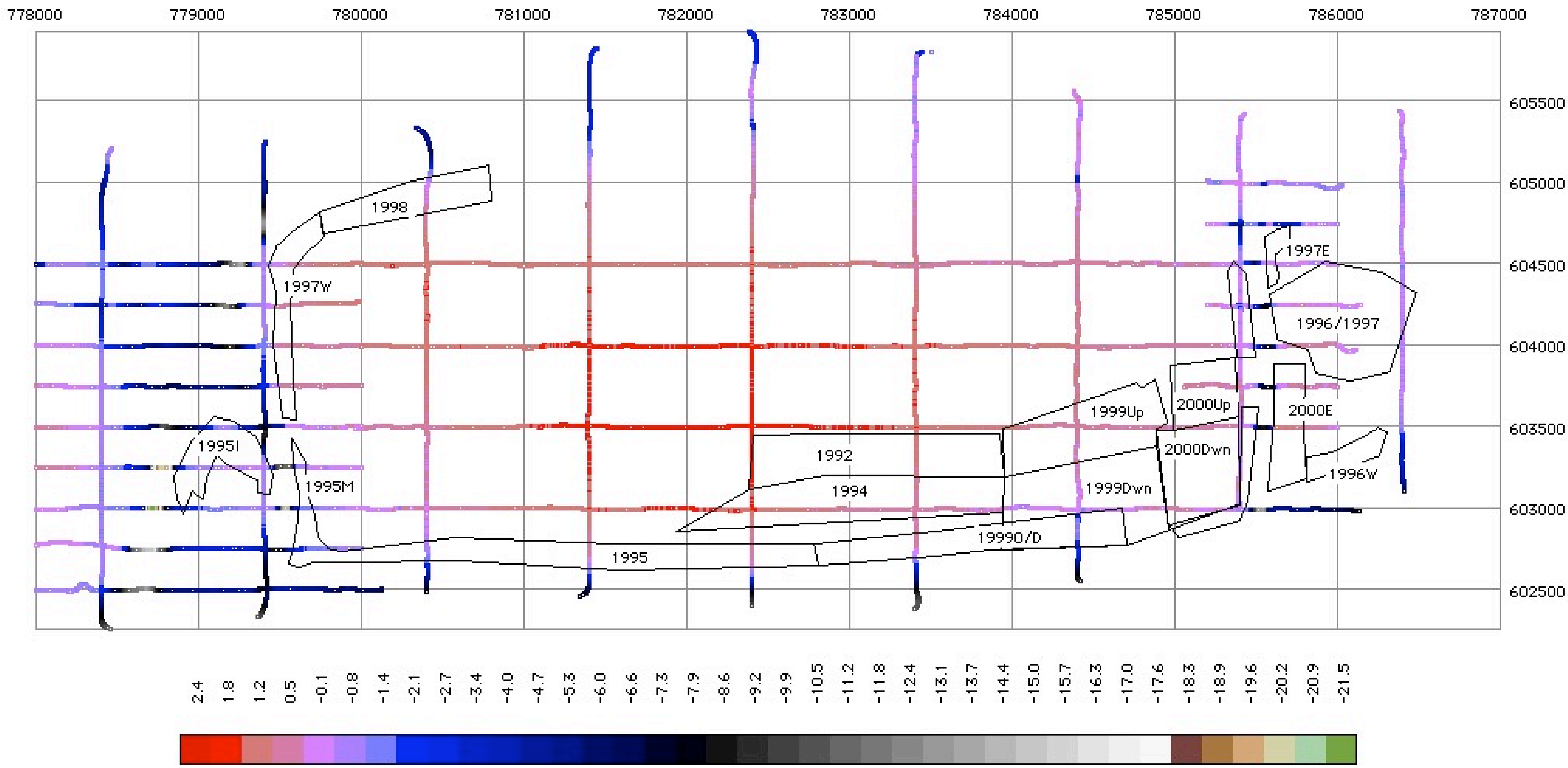


Figure 2. South Channel shell mitigation plots, showing survey paths from 2002 survey data and color-coded depth information.

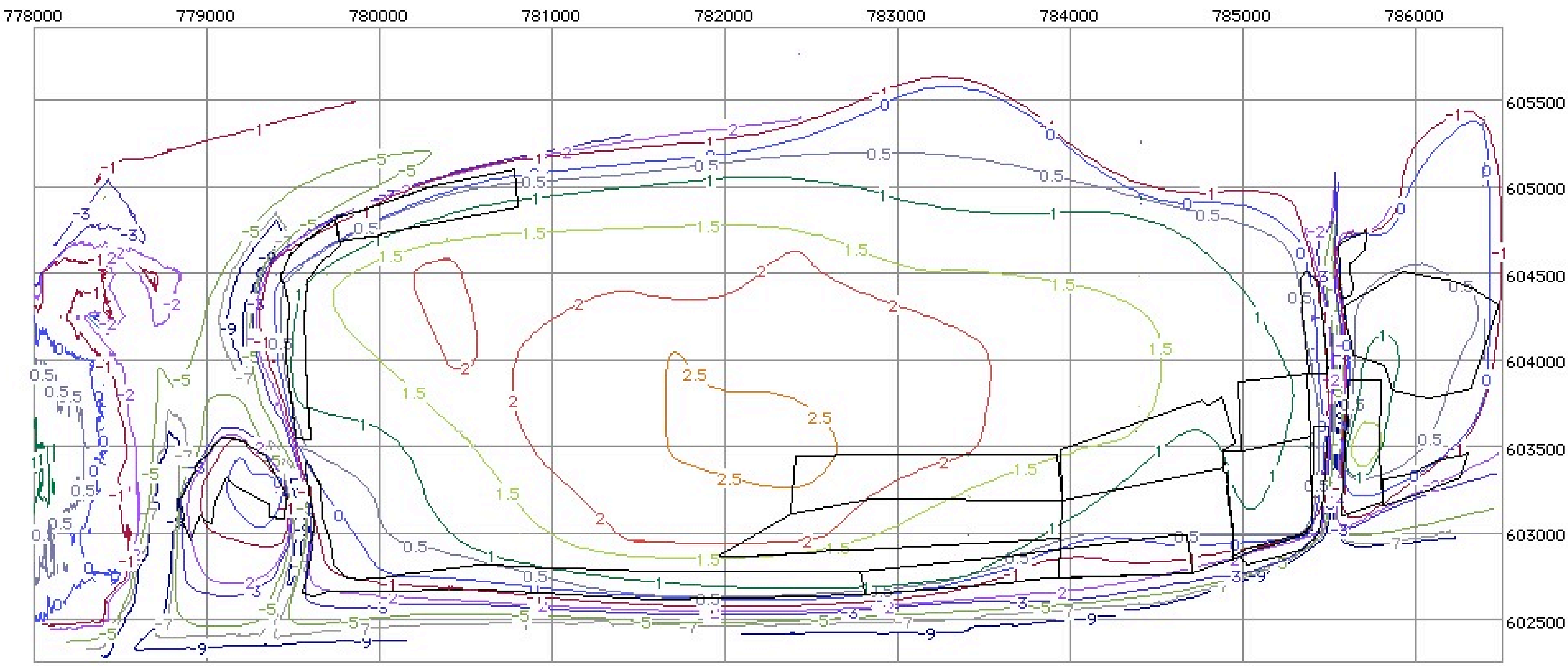


Figure 3. Depth contours for South Channel shell mitigation site and plot boundaries.

A regression of annual production per m^2 for new shell plots versus tidal elevation of the plot showed an r^2 value of 0.276 (Figure 4). J4 instars has historically been the production unit, and we continue to use this age class as the unit to predict and measure production. While not necessarily an impressive fit, considering the myriad of factors contributing to J4 production, particularly larval supply and percent shell cover, it was surprising to find that tidal elevation of the plot alone explained 27% of the variability in new shell productivity over eleven years. When all shell plots, both new and old, were considered, a simple linear regression explained less of the variability in the production per m^2 data (only 3-18% of the variability depending on inclusions of apparent outliers). This follows from the fact that as the shell habitat ages, several factors including percent shell cover and competition with *Hemigrapsus oregonensis* have a greater effect on the viability of the refuge space.

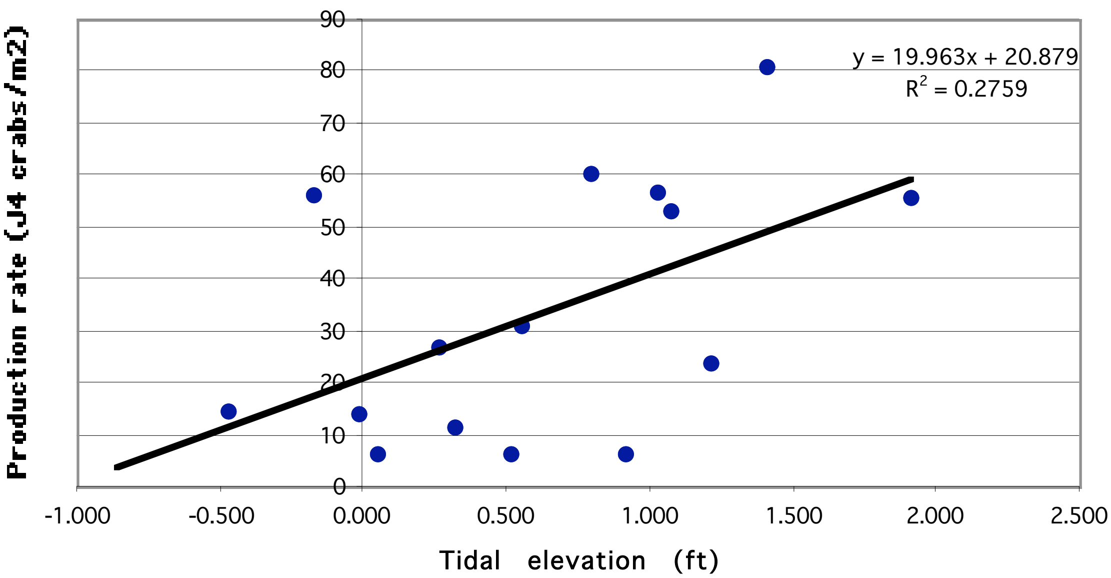


Figure 4. Tidal elevation versus shell mitigation plot productivity for new shell in the first year after construction only. If the apparent outlier of 81 crabs/m^2 for 1994 new shell is removed from the analysis, the regression equation becomes y = 14.86x + 21.52 with an r^2 of 0.190.

2002 data

Production was computed using the now standard J4 production model developed by Armstrong et al (1995) and modified in 1998 (Visser and Armstrong 1998). Total production for 2002 was fairly low, with a total of only 0.49 $\pm$ 0.10 million crab produced on all nine plots sampled (Table 4). It must be taken into account, however, that no new habitat has been created since April 2000, so the newest habitat available for settlement was two years old. Production ranged from 124, 510 crabs on the 1996/1997 plot to a low of 33, 512 crabs on the 1997 East plot (Figure 5).

Table 4. Summary data for 2002 production model. Production is in units of numbers of J4 juvenile Dungeness crab instars.

Habitat	Month	J2 /m2	Sd	Mortality	Area	Shell	sd	Production	Early	Total Prod	sd
1995 Island	May	0.00	0.00	0.0157	15522	0.67	0.31	0	0	77507	31187
	June	7.00	8.23	0.0157	15522	0.75	0.26	55263			
	July	3.00	6.75	0.0157	15522	0.66	0.31	39778			
	August	2.00	4.22	0.0157	15522	0.72	0.30	27065			
1995 Mainlanc	May	0.00	0.00	0.0023	7747	0.47	0.21	0	0	45409	19351
	June	7.00	8.23	0.0023	7747	0.49	0.24	28565			
	July	5.00	7.07	0.0023	7747	0.37	0.20	18823			
	August	3.00	6.75	0.0023	7747	0.36	0.18	17574			
1996/1997	May	0.00	0.00	0.0122	42662	0.22	0.14	0	6821	104002	55175
	June	11.00	12.87	0.0122	42662	0.20	0.14	73049			
	July	6.00	5.16	0.0122	42662	0.21	0.13	29892			
	August	0.00	0.00	0.0122	42662	0.29	0.17	0			
1997 East	May	0.00	0.00	0.0146	8671	0.27	0.26	0	0	31986	23884
	June	16.00	13.50	0.0146	8671	0.28	0.26	19966			
	July	4.00	5.16	0.0146	8671	0.23	0.21	6313			
	August	2.00	4.22	0.0146	8671	0.33	0.29	7233			
1999 Up	May	0.00	0.00	0.0072	32566	0.17	0.14	0	6925	62153	35133
	June	10.00	9.43	0.0072	32566	0.12	0.10	29313			
	July	8.00	12.29	0.0072	32566	0.10	0.08	30856			
	August	1.00	3.16	0.0072	32566	0.16	0.08	12824			
1999 O/D	May	0.00	0.00	0.0063	29562	0.08	0.14	0	0	28202	47640
	June	10.00	17.00	0.0063	29562	0.10	0.19	39952			
	July	3.00	6.75	0.0063	29562	0.07	0.11	10565			
	August	0.00	0.00	0.0063	29562	0.07	0.12	0			
2000 Up	May	0.00	0.00	0.0144	13912	0.58	0.18	0	0	57747	23353
	June	10.00	9.43	0.0144	13912	0.49	0.18	38945			
	July	5.00	7.07	0.0144	13912	0.39	0.18	23249			
	August	0.00	0.00	0.0144	13912	0.50	0.21	0			
2000 Down	May	0.00	0.00	0.0075	25175	0.30	0.21	0	0	41251	28016
	June	6.00	8.43	0.0075	25175	0.27	0.19	43887			
	July	3.00	4.83	0.0075	25175	0.17	0.14	16141			
	August	0.00	0.00	0.0075	25175	0.26	0.20	0			
2000 East	May	0.00	0.00	0.0078	13695	0.68	0.25	0	0	45523	19613
	June	4.00	5.16	0.0078	13695	0.67	0.23	35898			
	July	3.00	4.83	0.0078	13695	0.57	0.23	28526			
	August	0.00	0.00	0.0078	13695	0.60	0.20	0			
									TOTAL	**493780**	100899

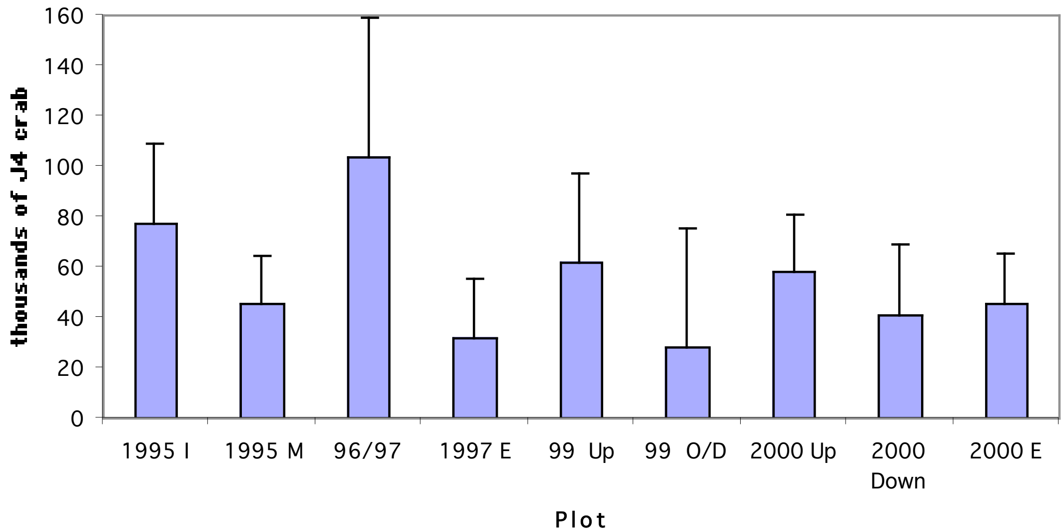
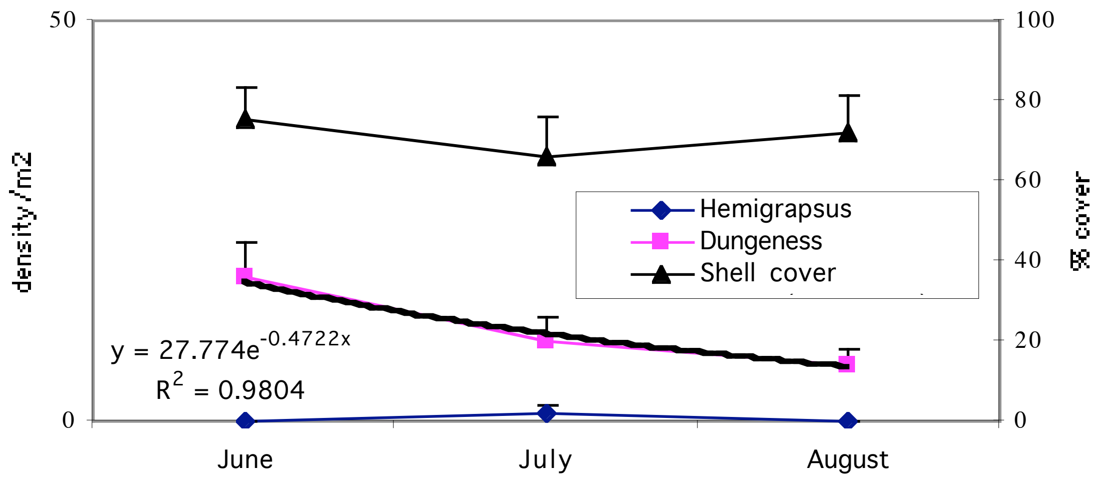


Figure 5. Production (thousands of J4 crabs) by plot for each of the nine plots sampled during summer 2002.

Crab density and instar composition data show that while larval supply was relatively low during late spring 2002, densities did not drop off sharply over the course of the summer. These fairly flat crab density functions (Figures 6-14) are resulted in the low mortality rates compared to other years (see Table 7). Some settlement occurred all summer, as evidenced by the presence of J1s every month sampled, especially the 2000 Down plot (Figure 12). Peak settlement appears to have been in mid - late May or early June, as can be seen by the abundance of J1 instars in the samples taken on each plot (Figs. 6 - 14). This timing is more typical than the relatively late settlement peak of last year.



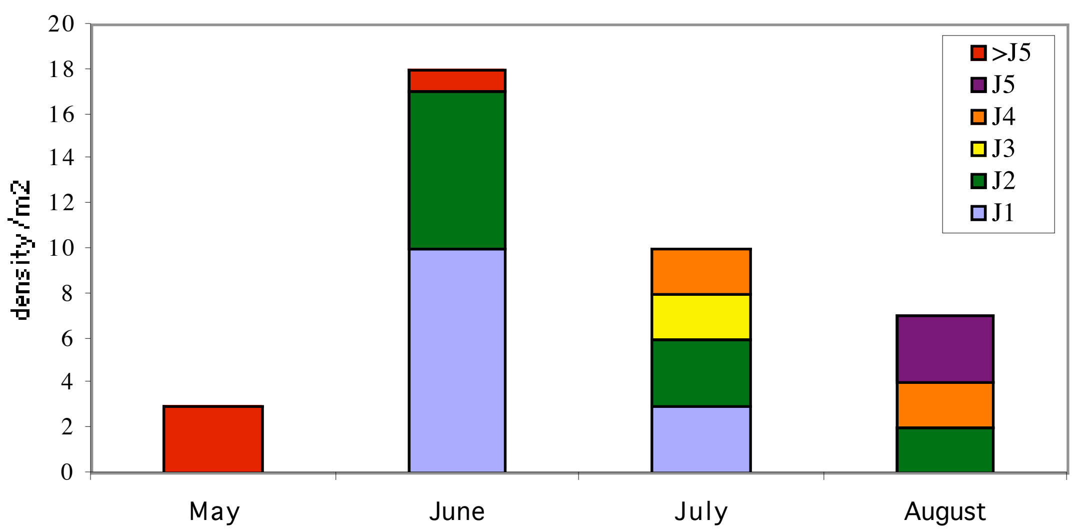
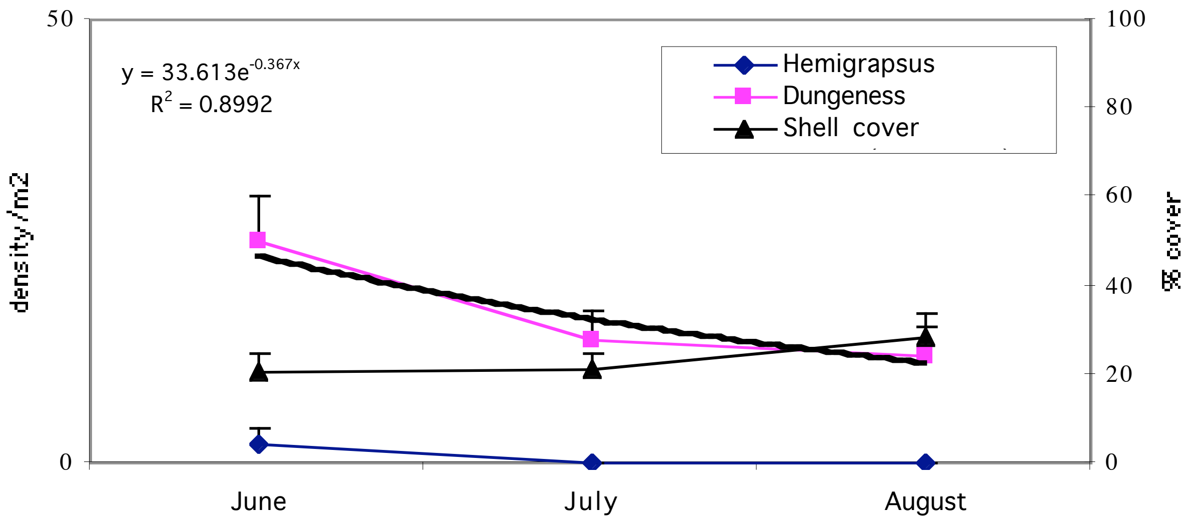


Figure 6. 1995 Island plot data: Dungeness and *Hemigrapsus* densities, percent shell cover, and Dungeness crab instar compositions for May through August 2002.



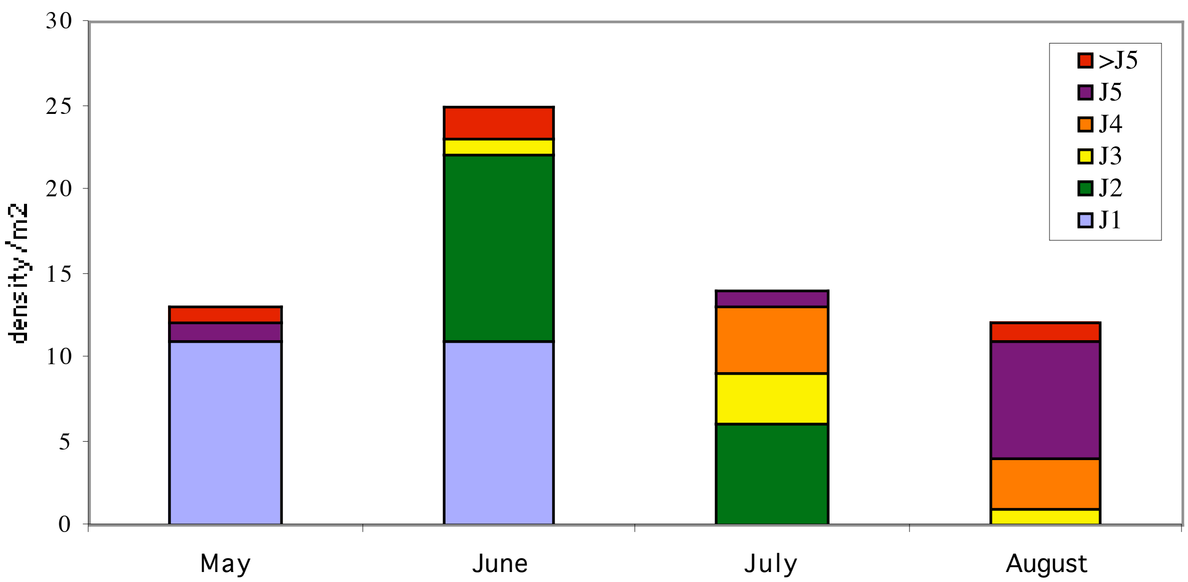


Figure 7. 1996/1997 plot data: Dungeness and *Hemigrapsus* densities, percent shell cover, and Dungeness crab instar compositions for May through August 2002.

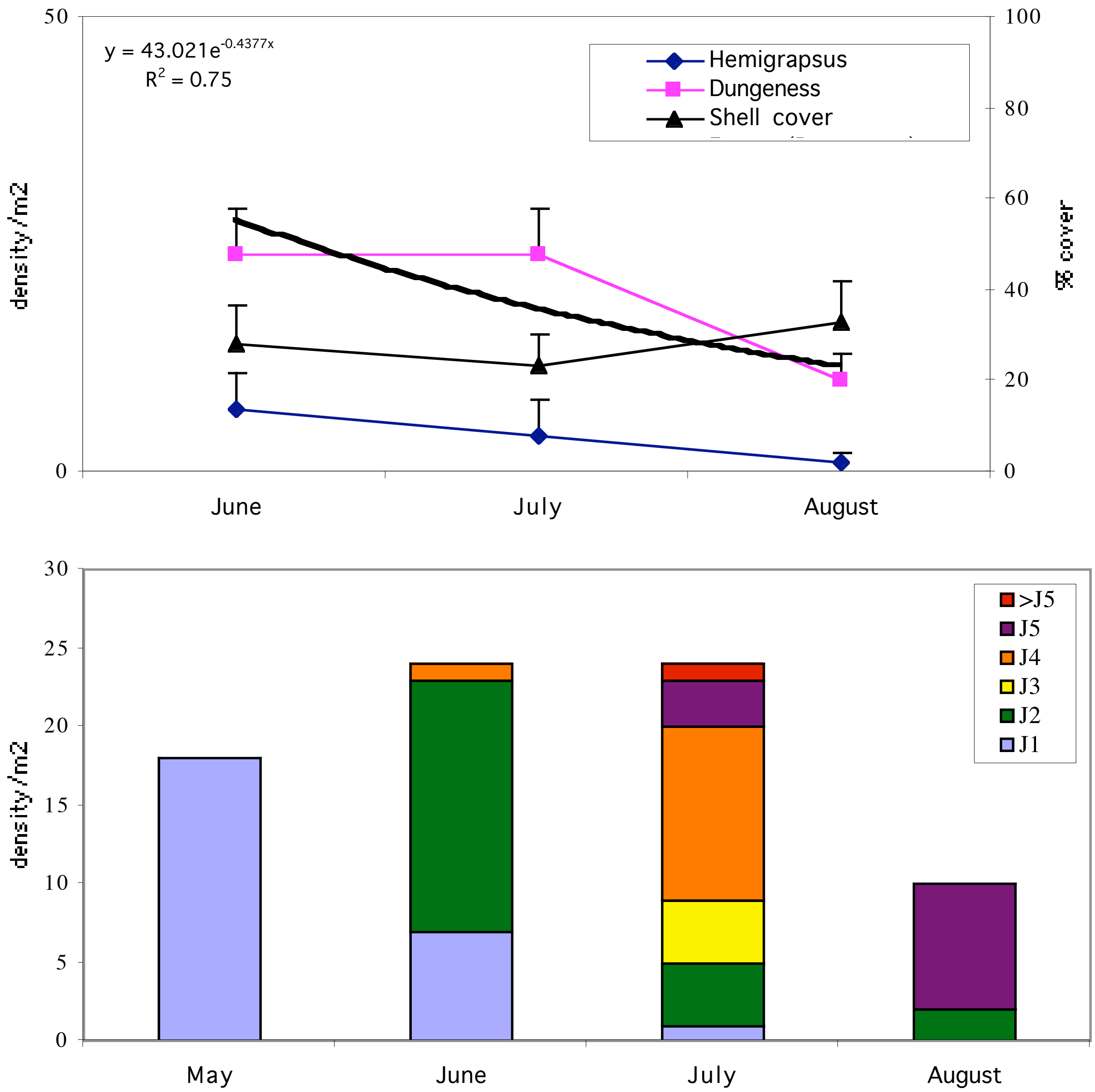
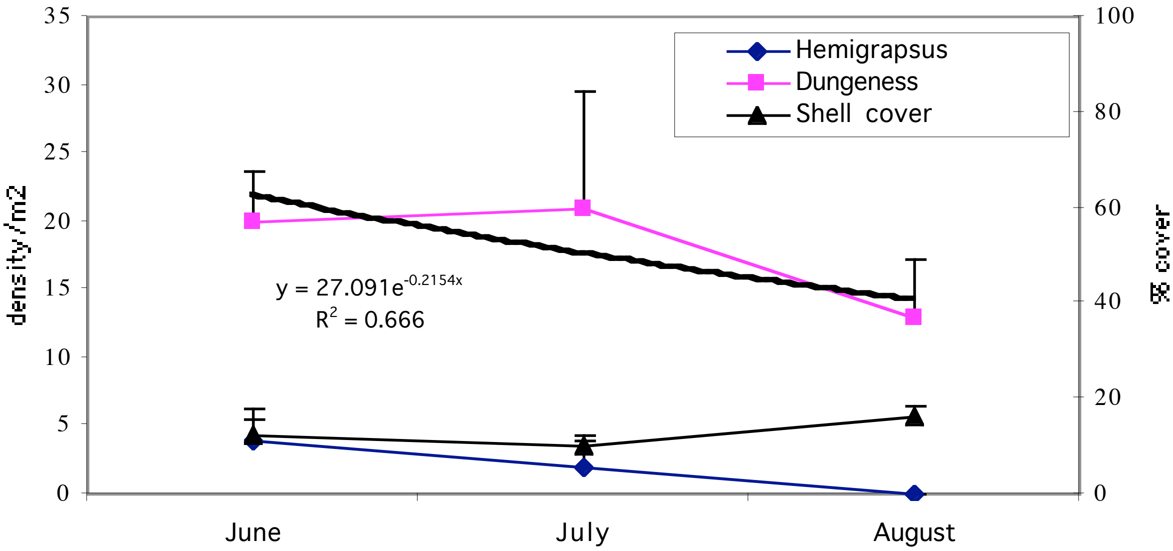


Figure 8. 1997 East plot data: Dungeness and *Hemigrapsus* densities, percent shell cover, and Dungeness crab instar compositions for May through August 2002.



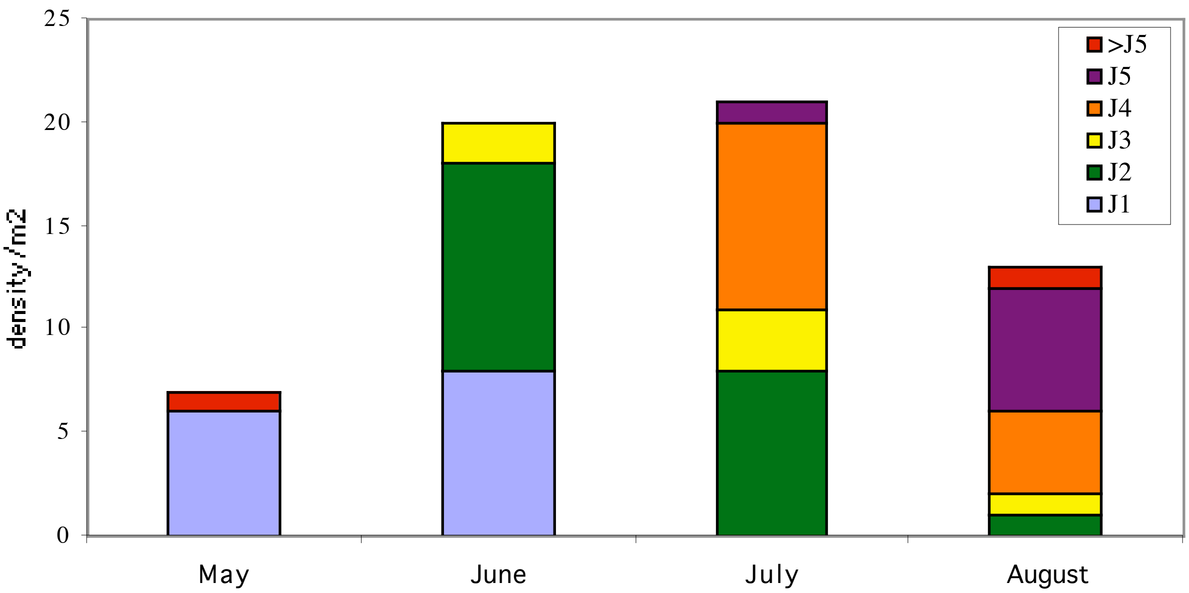


Figure 9. 1999 Up plot data: Dungeness and *Hemigrapsus* densities, percent shell cover, and Dungeness crab instar compositions for May through August 2002.

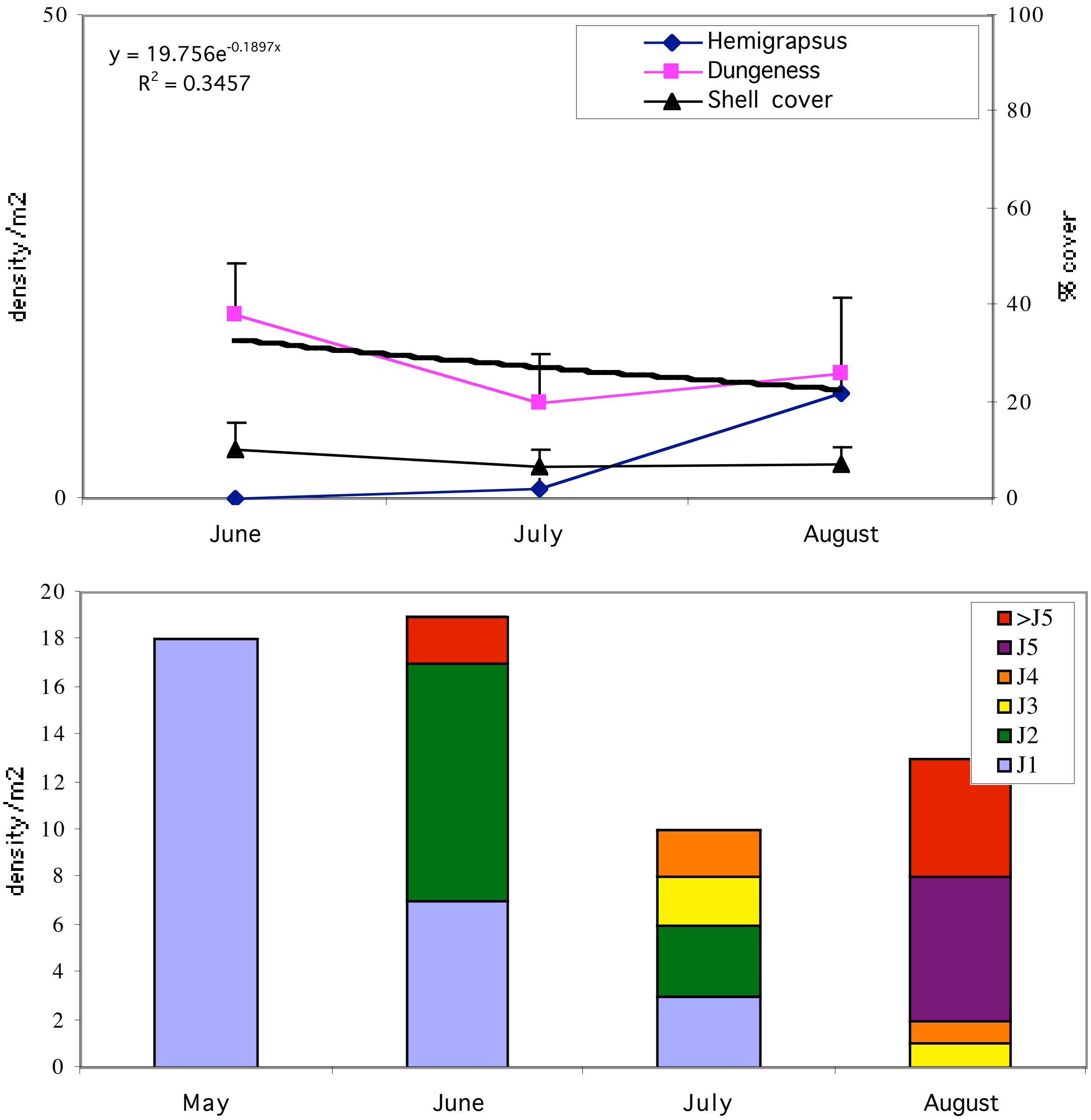


Figure 10. 1999 O/D plot data: Dungeness and *Hemigrapsus* densities, percent shell cover, and Dungeness crab instar compositions for May through August 2002.

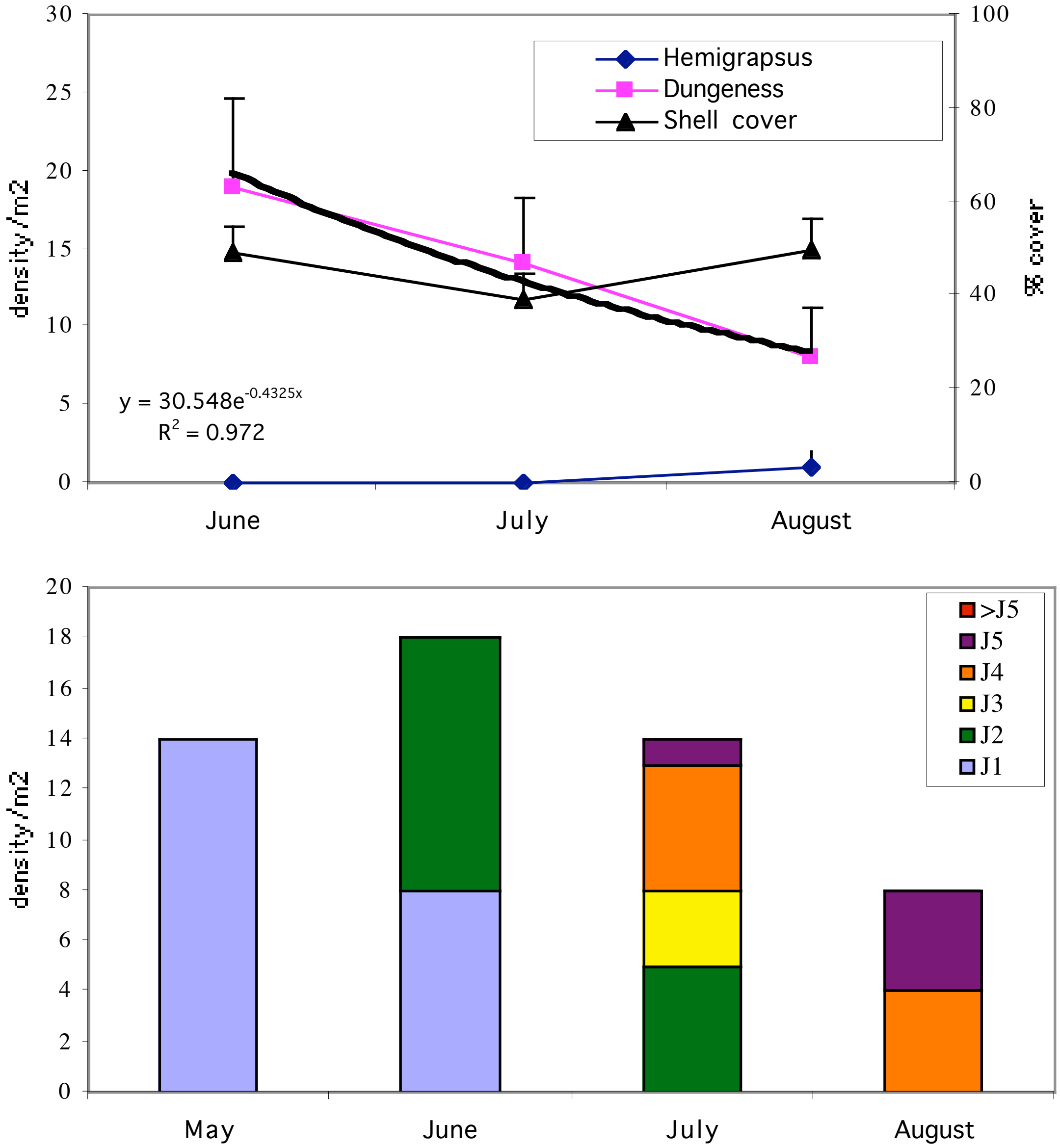


Figure 11. 2000 Up plot data: Dungeness and *Hemigrapsus* densities, percent shell cover, and Dungeness crab instar compositions for May through August 2002.

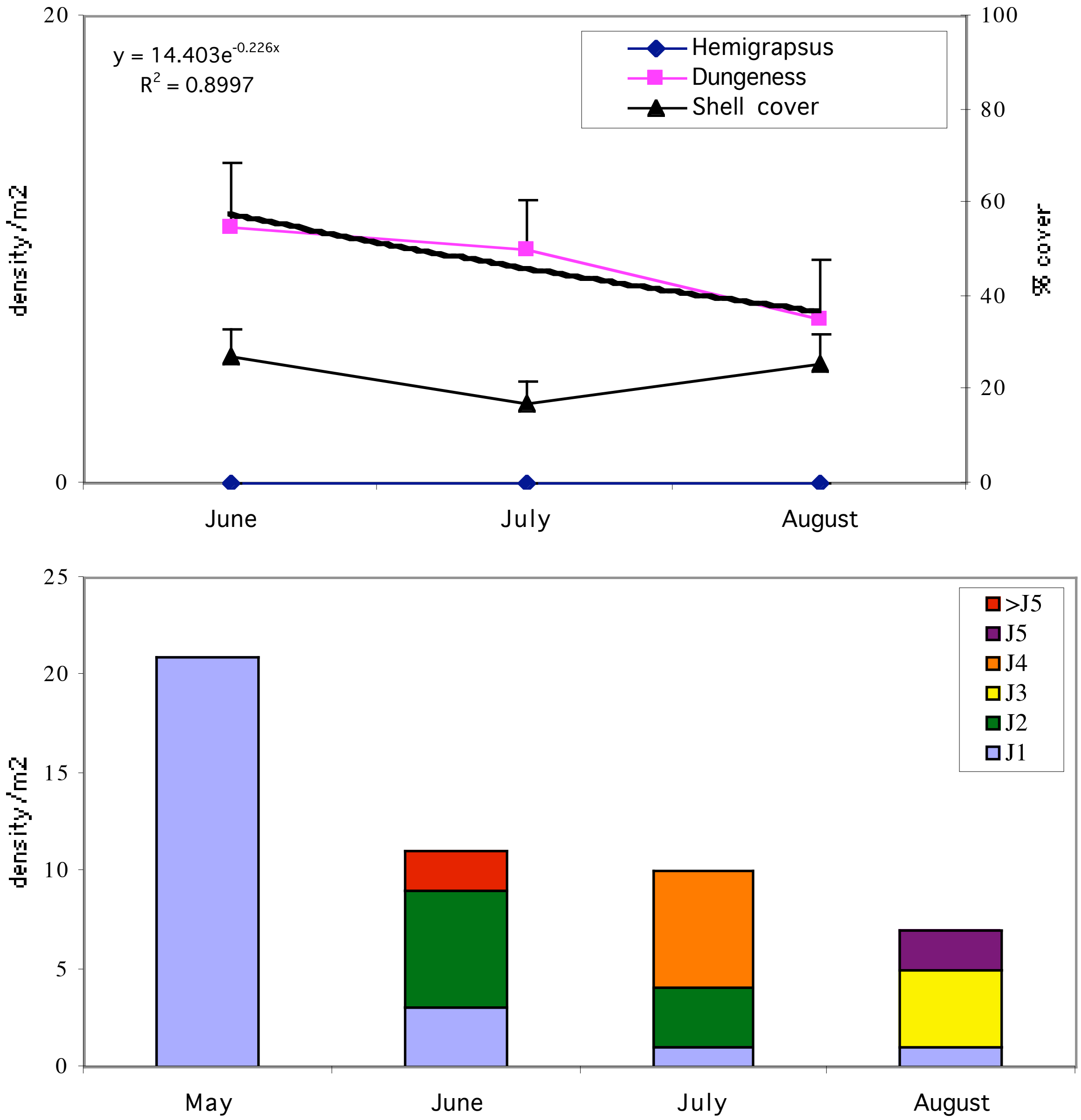


Figure 12. 2000 Down plot data: Dungeness and *Hemigrapsus* densities, percent shell cover, and Dungeness crab instar compositions for May through August 2002.

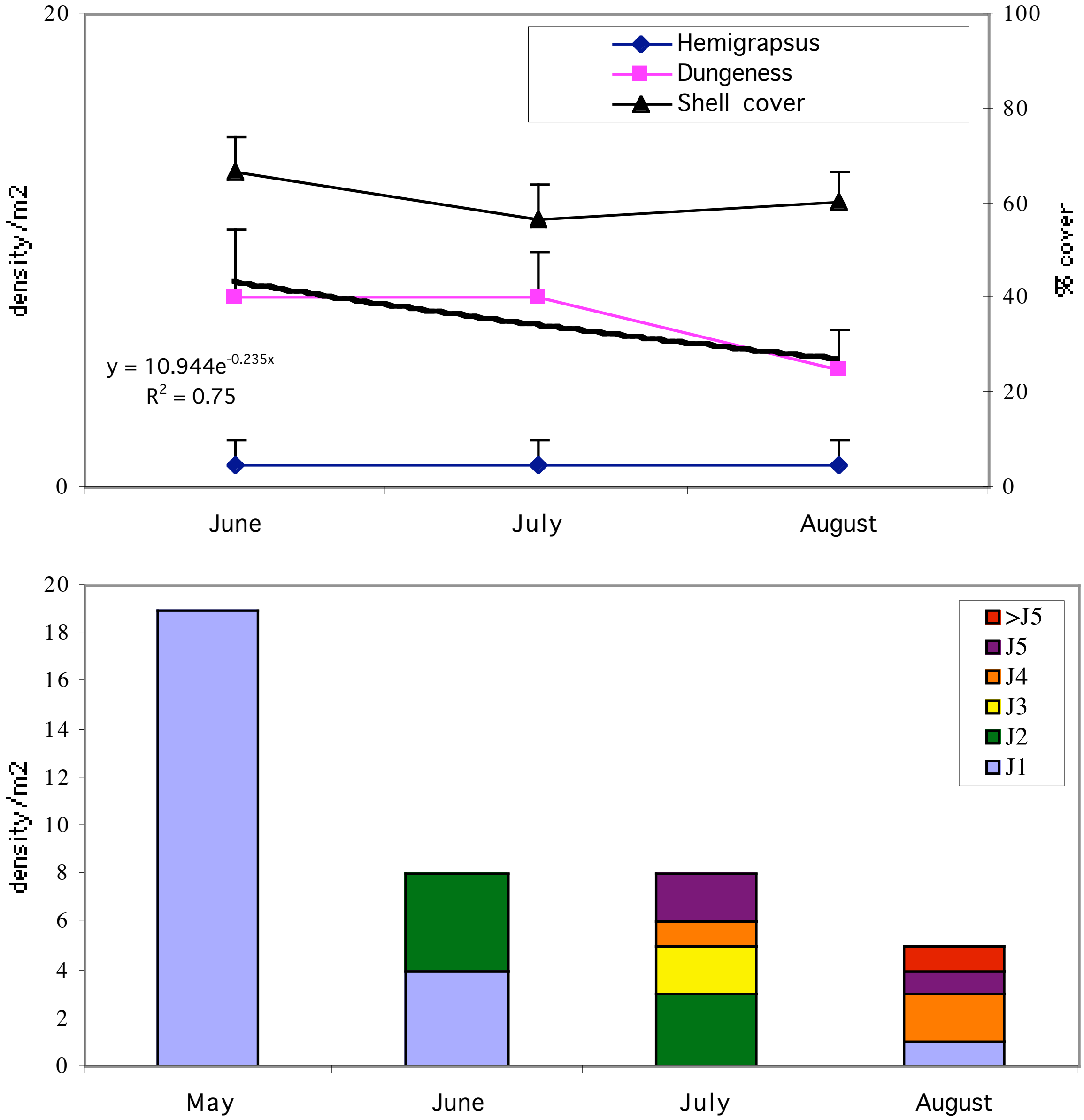


Figure 13. 2000 East plot data: Dungeness and *Hemigrapsus* densities, percent shell cover, and Dungeness crab instar compositions for May through August 2002.

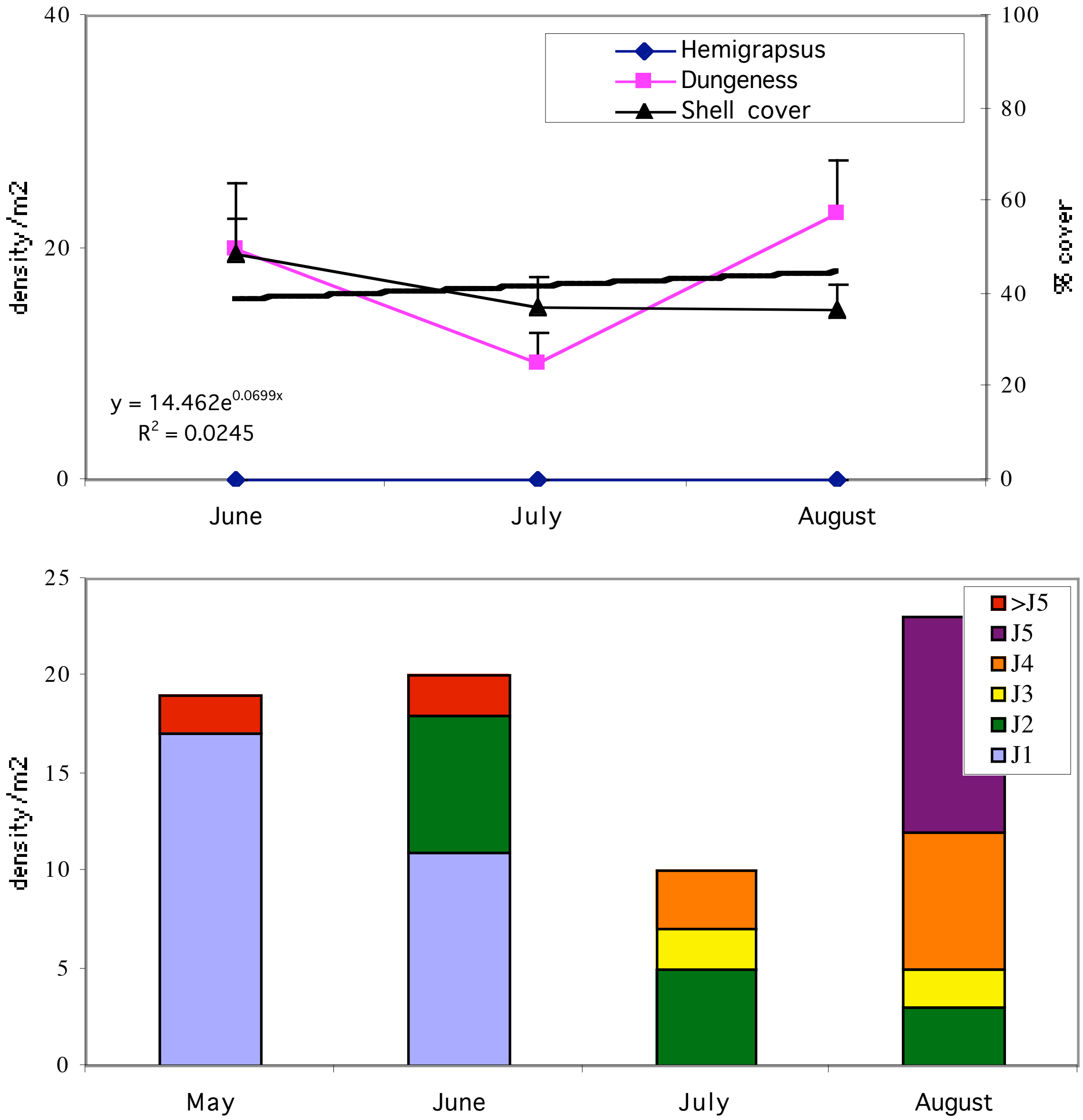


Figure 14. 1995 Mainland plot data: Dungeness and *Hemigrapsus* densities, percent shell cover, and Dungeness crab instar compositions for May through August 2002.

Shell cover data do not follow the expected trend of correlating with age of shell plot. On the contrary, one of the oldest plots sampled (the 1995 Island, which was seven years old at this sampling) had the highest shell cover of all shell plots sampled during summer 2002 (72%; Figure 6). Ranked order of shell plots based on most recent percent shell cover data are shown in Table 5. Slopes for percent shell cover were essentially flat over the 2002 sampling season when error bars are considered.

Table 5. Ranked order of plots according to percent shell cover during summer 2002. Blue data are for Group 1, black for Groups 2 and 3, which were grouped in the regression model since they were not statistically different from each other.

Plot	Percent shell
1990	0.00
1996W	0.01
1996E	0.10
1995	0.50
1998	2.00
1992	2.50
1997W	4.66
1994	6.50
1999 O/D	7.07
1999 Up	16.01
2000 Down	25.56
1996/1997	28.59
1997 E	32.97
1995 M	36.47
2000 Up	49.78
2000 E	60.35
1995 I	71.75

Percent shell cover on all of the plots indicated little change from May through August, which is fairly typical of old shell plots. Any apparent trends in the mean are within the error bars, and this indistinguishable from constant shell density. This ranked order does not support a hypothesis of overlay as a means of increasing shell longevity, since the three overlaid plots here (2000E, 1996/1997, and 1999O/D) have very different percent shell cover in August and do not show consistently increased longevity of refuge habitat. Considering the range of sediment consistencies inherent in the distribution of these plots, as well as low sample size (only 3 plots) and differing times since placement, this lack of correlation does not seem to merit the abandonment of the overlay strategy.

Mortality rates

For the nine plots sampled this year, mortality rates ranged from a z of 0.0023 to 0.0157, and averaged 0.0098 (Table 6), which is equivalent to a survival rate of 71%. These mortality rates are lower than all but one historical value for old shell (1996). Even newly placed shell habitat has not shown such low mortality rates in the past.

Presumably, competition for refuge space was low among the crabs settling in 2002, since initial densities were low, but survival higher than seen historically (Table 7).

Table 6. Mortality rates for Dungeness crab on plots sampled in 2002.

Plot	Z
1995I	0.0157
1995M	0.0023
1996/1997	0.0122
1997E	0.0146
1999Up	0.0072
1999O/D	0.0063
2000Up	0.0144
2000Down	0.0075
2000E	0.0078
Average	0.0098

Table 7. Annual mortality rates for shell plots averaged across all new or old plots for each year. Survival is the proportion of crab surviving to J4 instars after the 35 day interval it takes to molt from J2 to J4. All values are for South Channel plots except for 1991 new shell, which was constructed at PacMan. Asterisks indicate years for which mortality rates were computed using past years data, either because too few samples were taken in that year (1993 and 1994), or because of unusual settlement patterns (1997 and 1999), which would have yielded negative mortality rates.

Year	New Shell	Survival	Old Shell	Survival
1990	0.0195	0.51	N/A	
1991	0.0276	0.38	0.0216	0.47
1992	0.0179	0.53		
1993	N/A		* 0.0216	0.47
1994	* 0.0187	0.52	* 0.0216	0.47
1995	0.0136	0.62	0.0248	0.44
1996	0.0123	0.65	0.0096	0.71
1997	* 0.0158	0.58	* 0.0187	0.52
1998	0.0208	0.48	0.0343	0.30
1999	* 0.0168	0.56	* 0.0226	0.45
2000	0.0216	0.47	0.0197	0.52
2001	N/A		0.0321	0.33
2002	N/A		0.0098	0.71

Long range trends

Total production (total number of J4 crabs produced annually) has generally been highest in years with new shell construction, although 2001, when no new shell was placed, was an obvious exception (Figure 15). 2002 production, with just under 0.5 million crabs, is a result of no new shell placement for two years, and relatively low larval supply this year. Even the exceptionally low mortality rates this year could not make up for the effect of these other factors.

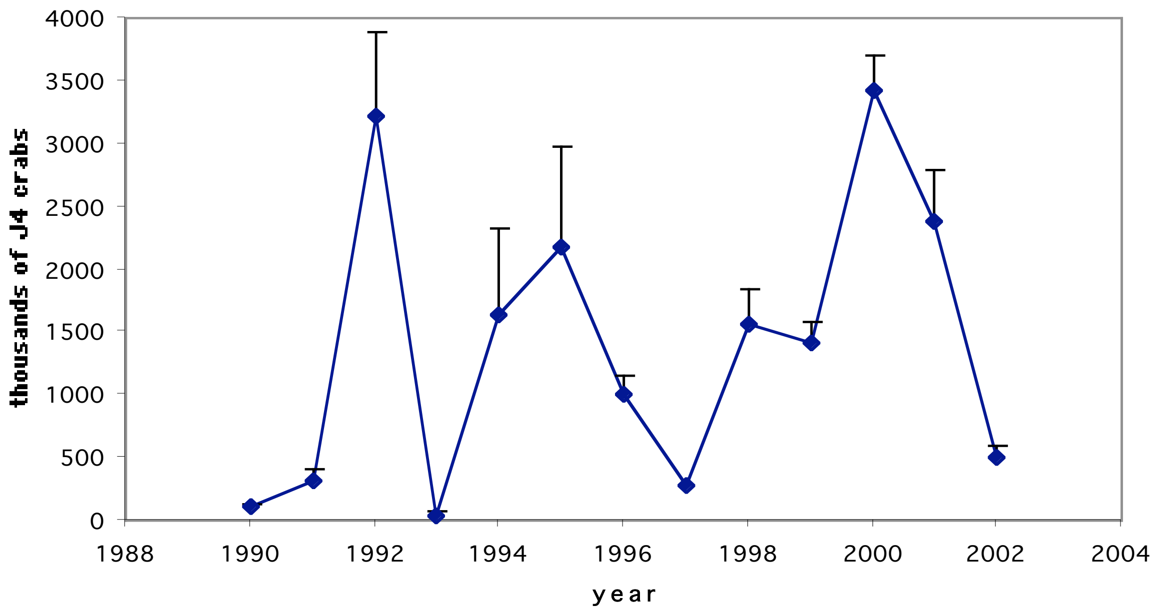


Figure 15. Total J4 crab production (from new and old plots sampled) since the beginning of mitigation efforts in South Channel. New shell was placed in all years except 1991, 1993, 2001, and 2002.

The negative impact of *Hemigrapsus oregonensis* on productivity of *Cancer magister* on the shell mitigation plots seems to have reversed itself in recent years (Figure 16). Crab density data from 1998-2001 suggested a recruitment failure of *H. oregonensis* and a return to the *C. magister* densities and population dynamics seen in the initial years of the mitigation project (1990-1991) when *H. oregonensis* had not yet colonized the plots (Figure 17). The only direct larval settlement data available for the region are from larval light traps placed and sampled in Coos Bay, Oregon during 1998-2001. These data indicated a continual drop in *H. oregonensis* larval supply from 1998 to 2001 (C. Roegner, pers.comm.). Unfortunately, there are no similar data for Grays Harbor itself, nor data prior to 1998 for Coos Bay for comparison of the two phases (1992-1997 versus 1998-2002). While Coos Bay is several hundred miles south of Grays Harbor, these data suggest a possible cause of the decline in *H. oregonensis* in Grays Harbor. It would be interesting to compare historical versus present *H. oregonensis* densities for other locations along the Washington and Oregon coast and also to compare larval recruitment data for Grays Harbor and Willapa Bay with those of Coos Bay.

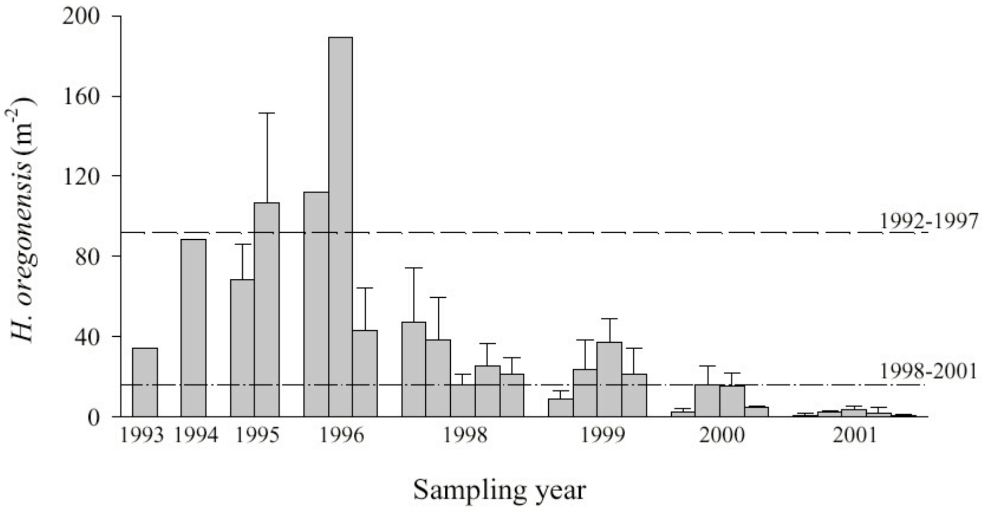


Figure 16. *Hemigrapsus oregonensis* density in shell mitigation samples over time, showing decline, and apparent recruitment failure since 1998 (Visser et al., in review).

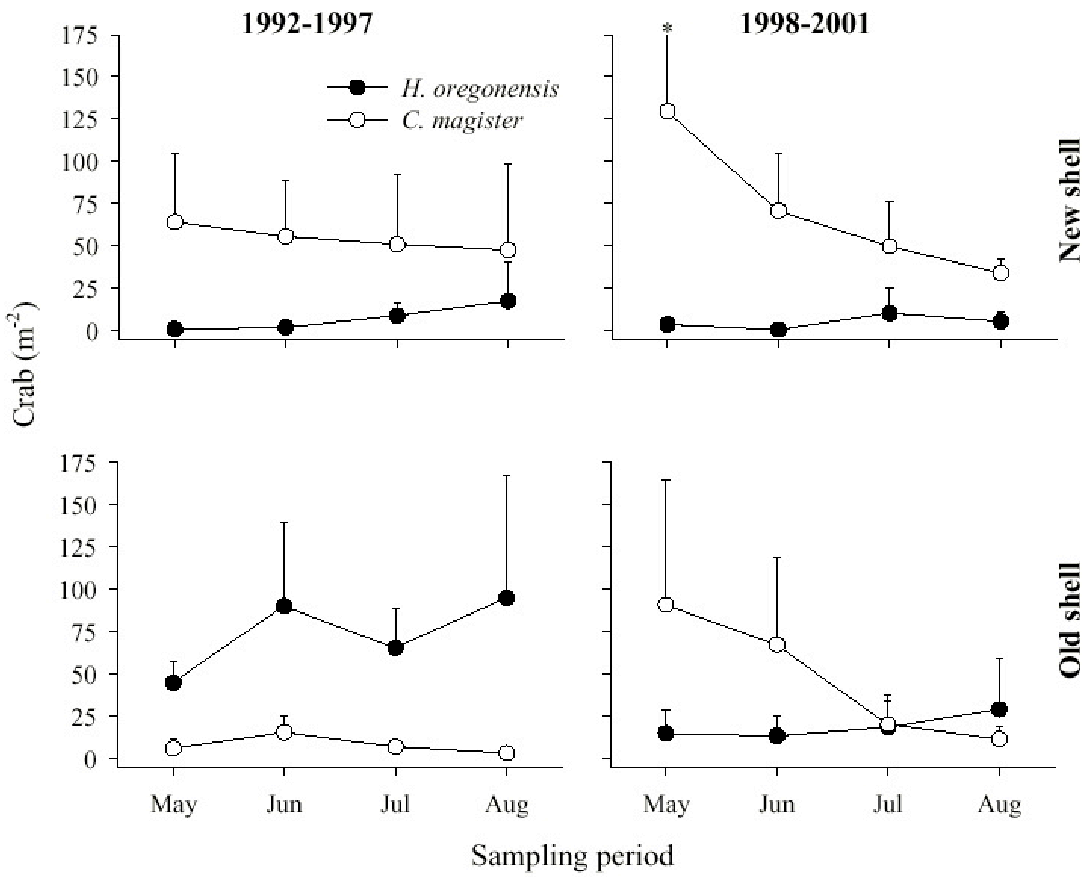


Figure 17. *Cancer magister* and *Hemigrapsus oregonensis* densities in shell mitigation habitat during the two phases of the project, showing the reversal in Phase II in usage of old shell to patterns formerly more typical of new shell (Visser et al., in review).

The original mitigation goal was 10 crabs/m^2 for constructed habitat. During the early phase (Phase I: 1992-1997) of the project, competition with *Hemigrapsus oregonensis* decreased habitat use by Dungeness crab compromised the effectiveness of the plan and only 12% of old shell plots and 71% of new shell plots met or exceeded this goal. During the second phase (Phase II: 1998-2002), 21% of old plots and 100% of new plots have met or exceeded the initial expectations (Table 8).

Table 8. Number of plots producing more than 10 crabs per m^2 and less than 10 crabs per m^2 during the two phases of the project.

	Phase I		Phase II	
	≥10	<10	≥10	<10
New shell plots	5	2	3	0
Old shell plots	1	7	4	15

The old shell plots exceeding the goal were the 1990 plot sampled in 1991, the 1997 plot sampled in 1998 and again when sampled in 2001, the 1995 Island plot sampled in 2001, and the 2000 plots sampled in 2001 (Figure 18). New shell plots which exceeded the goal in their first year were the 1990, 1991, 1992, 1994, 1995, 1998, 1999, and 2000 plots.

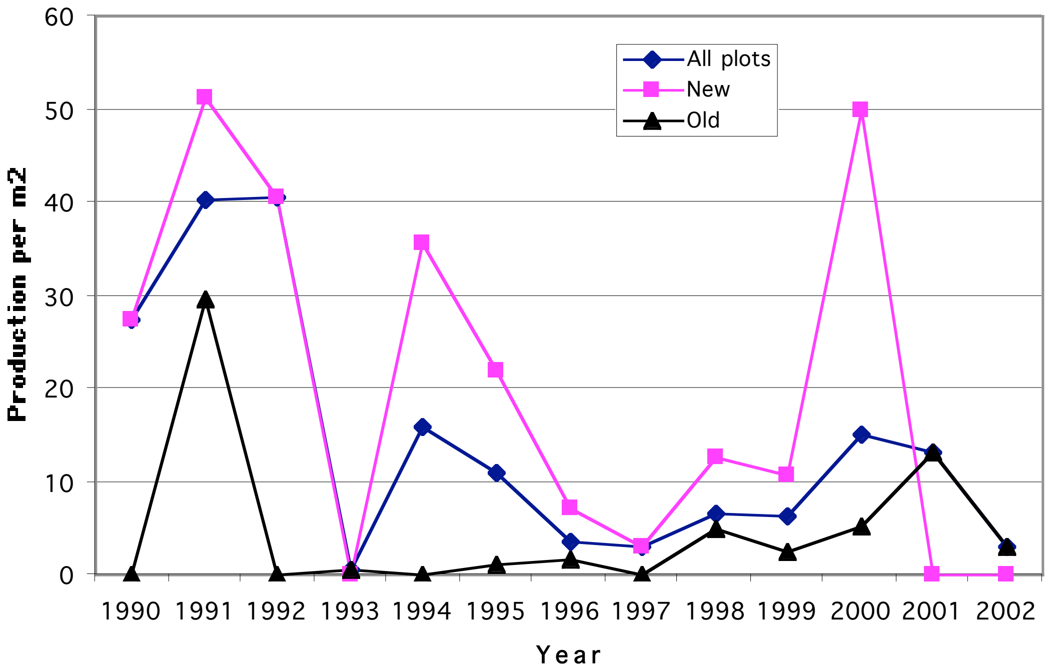


Figure 18. Average production rates (J4 crabs per m^2) for new, old, and all plots over the 13 year sampling history of the mitigation project since 1990. While new shell consistently produces more crabs per unit of habitat, there is much fluctuation among new shell plots and among old shell plots themselves. Age of shell alone does not correlate well with productivity. Zero values indicate either no new shell placement (2001 & 2002) or no sampling effort (1997 old shell).

Value:cost estimates

Dinnel (1996) computed the expense to replace each equivalent adult male crab killed by ACOE dredging (1+ crab computed as surviving 3+ legal males, each worth about $1.34 per pound, or $3.09 per crab ex-vessel) averaged about $50 per crab from 1992-1995, although they consider their value:cost ratios an extreme since the value of the crab increase by 3-5 fold as they move through the fisherman to consumer chain. Dinnel's production calculations also predate the production model (Armstrong et al. 1995a; Visser and Armstrong 1998) which gives 50% higher production estimates compared to the simple August standing stock method used previously (Dinnel 1996). Dinnel's report gives description of computations and discussion of factors.

Updated value:cost ratios for 1998 -2002 indicate a cost less than $0.20 per J4 crab for mitigation, although still a significant total amount considering the number of crabs produced during this period (about 9 million). Costs for mitigation efforts and resulting crabs produced since 1998 are shown in Table 9.

Table 9. Project costs compared with crab production rates over the past five years.

Year	Placement	Perkins Point	G.H. College	Production
1998	$100,000	$27,645	$24129	1,555,565
1999	$531,400	$23,484	$21332	1,466,749
2000	$417,008	$42,286	0	3,416,889
2001	0	$50,038	0	2,382,476
2002	0	$52,617	0	493,780
Sum			$1,289,939	9,315,459

The resultant average cost over the past 5 years was $0.14 per J4 juvenile produced, which is surprisingly low considering that two of these five years had no new shell habitat for crab to utilize. While still a significant expenditure and endeavor, the disparity between the value of the resource impacted b dredging and the cost to mitigate these losses has diminished.

RECOMMENDATIONS FOR SHELL PLACEMENT

Overlay

Good idea. Despite the failure to prove a significant improvement in plot productivity so far, placing shell over a basement of existing shell habitat cannot decrease shell stability, and may slow shell sinkage rates. Particularly considering the recent recruitment failure of *Hemigrapsus oregonensis*, which reduces the likelihood that old shell will harbor source populations of *H. oregonensis* and associated competition will compromise effectiveness of refuge habitat. Utilizing the overlay technique may improve productivity and has little to no potential for decreasing it.

Tidal elevation
Target areas > 1 ft. above mean lower low water. Evidence suggests that high tidal elevation positively correlates with production rates in the first summer after shell placement, and that an increase of 1 ft of elevation increases per m^2 production by a factor of 15-20 over the first summer.

Shell cover
Place shell on areas where current shell cover is low, attempt even distribution when laying new habitat and target plots from Groups 2 and 3. Percent shell cover is the single strongest factor contributing to productivity. While shell longevity depends upon sediment stability, shrimp density (Feldman et al. 1997, Feldman et al. 2000), sedimentation processes, storm patterns, etc. and is hard to influence, initial percent cover should be as close to 100% as possible. Placing new shell on areas with very low percent cover will maximize productivity from old shell plots and increase the overall amount of refuge habitat available after placement of new shell. The MiniTab model fit to the production data by William Hooper's statistics class at Clarkson University suggests that a given amount of shell habitat placed in plots from Groups 2 and 3 produces more juvenile crabs than does the same amount of shell habitat placed in Group 1 plots.

Historical sites
Consider unexplained historical performance in production as a tie-breaker criteria. There are many factors influencing the productivity of shell mitigation plots that are not fully understood. Even with 13 years of data in this project, we cannot predict in advance which areas or plots will be the most productive, since there are many options which optimize productivity based on the known information and trends in the data. Of these options, choosing ones that have performed well historically seems wise, even if the specific reasons for this productivity remain unknown. Of the six plots that have produced more than 20 crabs/m^2 at least once since their construction (1990, 1991, 1992, 1994, 1995, 2000; Figure 19), one (the 1991 plot) is not located at South Channel. It is not feasible to consider shell placement at the PacMan site at this time. Another of the plots, the 1990 plot, is very small (only 4000 m^2) and even if the production rate proved high, the total production from such a small plot is unlikely to exceed a maximum total of 100,000 crabs, even in its initial year.

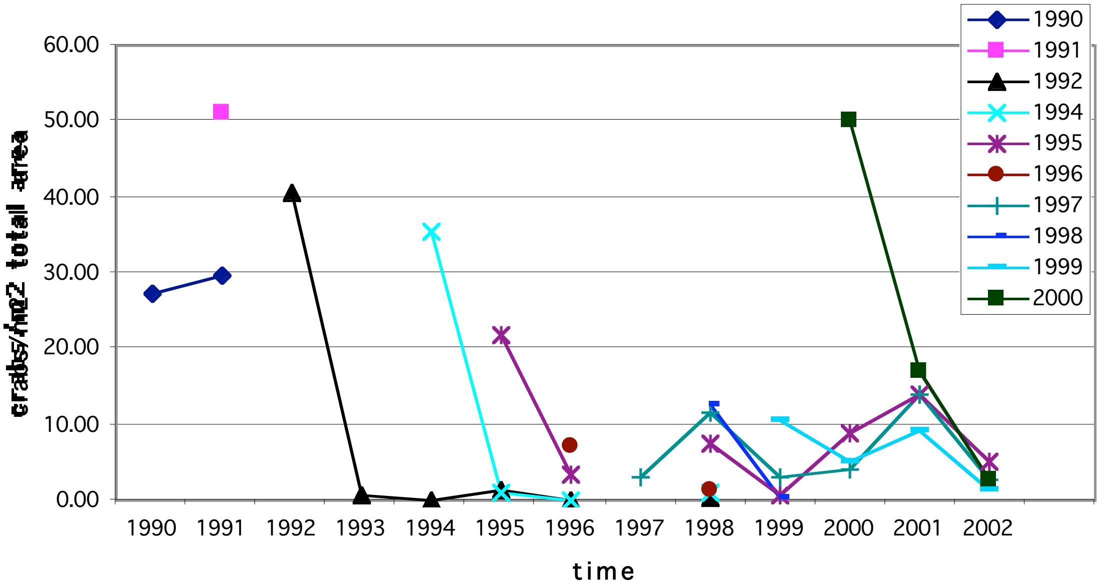


Figure 19. Plot production rate over time for total area of habitat constructed, not corrected for percent shell cover. The legend shows symbols for each habitat, for example the green square is the shell habitat constructed in 2000, which can be seen on the graph as producing 50 J4 crabs per m^2 its first year, and then 17 J4 crabs per m^2 in 2001 when it was 1 year old.

Priority for 2003 placement: Based on all of the above criteria, the 1994 and 2000 Down plots are the best choices for maximization of production, both for 2003 summer production, in the initial year of construction as well as the most likely to produce well over time. Both 1994 and 2000 Down plots currently have less than 30% shell cover, and both are in the Groups 2 or 3, emerging from the MiniTab analysis as primary placement targets. Both plots are in the upper half of the elevation range available for shell placement at South Channel (above 0.524 feet). In addition, these plots had extremely high production per m^2 rates in their initial years (35.5 crabs/m^2 for the 1994 plot, and 49.81 crabs/m^2 for 2000 Down), and the 2000 shell performed much better than other plots generally do in its second year as well. Both of these plots should have minimal eelgrass coverage; <0.5% for the 2000 Down plot in August 2002. The 1994 plot should take priority, and 2000 Down as an overflow site if budgetary constraints allow more new shell placement than will cover the approximately 42,000 - 46,000 m^2 of the former 1994 area. The 2000 Down plot is approximately 25,000 m^2. The 1992 plot may be a good third option if more shell is available for placement. Although the plot is quite high, it fits the criteria listed here. Tables 10, 11 and 12 show GPS coordinates for these three plots, to assist in staking the boundaries for shell placement.

Table 10. GPS coordinates approximating the corners of the 1994 plot boundary.

Latitude	Longitude
46.9359	123.9359
46.9352	123.9376
46.9357	123.9296
46.9363	123.9296

Table 11. GPS coordinates approximating the boundary of the 2000 Down plot.

Latitude	Longitude
46.9356	123.9255
46.9361	123.9238
46.9376	123.9239
46.9372	123.9259

Table 12. GPS coordinates approximating the boundary of the 1992 plot.

Latitude	Longitude
46.9359	123.9359
46.9363	123.9296
46.9371	123.9298
46.9369	123.9358

References

Armstrong, D. A., M. Fernandez, and E. Visser. 1995. Estimated production of 0+ Dungeness crab (Cancer magister) in intertidal shell mitigation habitat, Grays Harbor estuary, 1990 to 1994. Final Report to the Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Armstrong, D. A., O. O. Iribarne, P. A. Dinnel, K. A. McGraw, A. Shaffer, R. Palacios, M. Fernandez, K. L. Feldman, and G. Williams. 1992. Mitigation of Dungeness crab, *Cancer magister,* losses due to dredging by development of intertidal shell habitat: pilot studies during 1991. FRI-UW-9205, University of Washington, Seattle, 36 p.

Dinnel, P. A. 1996. Historical perspective of the Grays Harbor crab mitigation project. Final report to David Evans and Associates and the Seattle District, U.S. Army Corps of Engineers, Seattle, Washington. 50 p.

Dumbauld, B. R., D. A. Armstrong, and T. L. McDonald. 1993. Use of oyster shell to enhance intertidal habitat and mitigate loss of Dungeness crab (Cancer magister) caused by dredging. Canadian Journal of Fisheries and Aquatic Sciences 50: 381-390.

Dumbauld, B. R., E. P. Visser, D. A. Armstrong, L. Cole-Warner, K. L. Feldman, and B. E. Kauffman. 2000. Use of oyster shell to create habitat for juvenile Dungeness crab in Washington coastal estuaries: status and prospects. Journal of Shellfish Research 19(1):379-386.

Feldman, K. L., D. A. Armstrong, B. R. Dumbauld, T. H. DeWitt, and D. C. Doty. 2000. Oysters, crabs, and burrowing shrimp: An environmental conflict over aquatic resources and pesticide use in Washington State's (USA) coastal estuaries. Estuaries 23 (2): 141-176.

Feldman, K. L., D. A. Armstrong, D. B. Eggleston, and B. R. Dumbauld. 1997. Effects of substrate selection and postsettlement mortality on recruitment success of the thalassinidean shrimp Neotrypaea californiensis to intertidal shell and mud habitats. Marine Ecology Progress Series 150: 121-136.

Visser, E.P. 2002. Grays Harbor Shell Mitigation Project 2001 Report Crab Mitigation Project: GPS corrected plot areas, 2001 crab data, production summaries, and monthly sampling breakdowns. Final Report to the U.S. Army Corps of Engineers, Seattle District Office, Seattle, WA. 47 pp. (http://www.nws.usace.army.mil/publicmenu/DOCUMENTS/2000_report.pdf)

Visser, E. P. 2001. Grays Harbor Shell Mitigation Project 2000 Report: Cumulative mortality and production updates, 2000 crab densities, instar composition, and shell cover. Final Report to the Army Corps of Engineers, Seattle District Office, Seattle WA. 40 pp. (http://www.nws.usace.army.mil/publicmenu/DOCUMENTS/2001Grays_Harbor_Crab_Mitigation_Report.pdf)

Visser, E. P., and D. A. Armstrong. 1998. Grays Harbor Shell Mitigation Project Status Report: *Cancer magister* and *Hemigrapsus oregonensis* densities, modified production model, and production estimates for summer 1998. Final Report to the Army Corps of Engineers, Seattle District Office, Seattle WA. 27 pp.

Visser, E. P., P.S. McDonald and D. A. Armstrong. In review, 2003. The impact of yellow shore crab, Hemigrapsus oregonensis, on intertidal habitat mitigation for early benthic phase Dungeness crab, Cancer magister. Estuaries submission #3685.

Wainwright, T. C., D. A. Armstrong, P. A. Dinnel, J. M. Orensanz and K. A. McGraw. 1992. Predicting effects of dredging on a crab population: An equivalent adult loss approach. Fishery Bulletin U.S. 90: 171-182.